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Environmentally Sound Harvesting Technologies in Commercial Forests in the Area of Northern Velebit – Functional Terrain Classification

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Abstract

Background and Purpose: *The role of environmental effects in timber harvesting has great importance in decision making and planning logging operations. Consequently, more emphasis should be put on a planning system so that environmentally sensitive sites for a certain harvesting system can be recognized and the most suitable machinery selected for given terrain conditions.*

Material and Methods: *Four main data sources have been used for the model of ecoefficient harvesting system prediction: 1) a digital elevation model (DEM), 2) a digital network of forest roads, 3) forest inventory data and 4) ecoefficient limitations for harvesting systems. Software ArcGIS 9 was used for GIS processing and data analysis.*

Results: *A model for selecting an ecoefficient harvesting system for commercial forests of Northern Velebit is based on three influencing factors: terrain slope, extraction distance and breast height diameter of trees. Based on the model, a harvesting system is determined for each forest subcompartment. The results show that breast height tree diameter restricts mechanized felling and processing. Fully mechanized harvesting systems could be used only over 7.27% of the researched area. Ground based extraction represents the main technology.*

Conclusions: *In order to establish functional terrain classification, a model for determining an ecoefficient harvesting system should comprise a geographic information system, and terrain and forest stand data. Specific terrain (limestone combined with relief characteristics) and forest stand conditions (mixed selective forests with natural regeneration) limit the application of some harvesting systems which would otherwise be environmentally acceptable in many other cases.*

INTRODUCTION

Timber harvesting, as a succession of interrelated and interdependent operations in timber production, includes tree conversion (felling and processing) and timber transport. Timber transport consists of two subphases: off-road (timber extraction) and on-road (further transport) that are mutually dependent. In the past, the phases were separated, but at present they occur at the same time. A harvesting system refers to the tools, equipment and machines used to harvest an

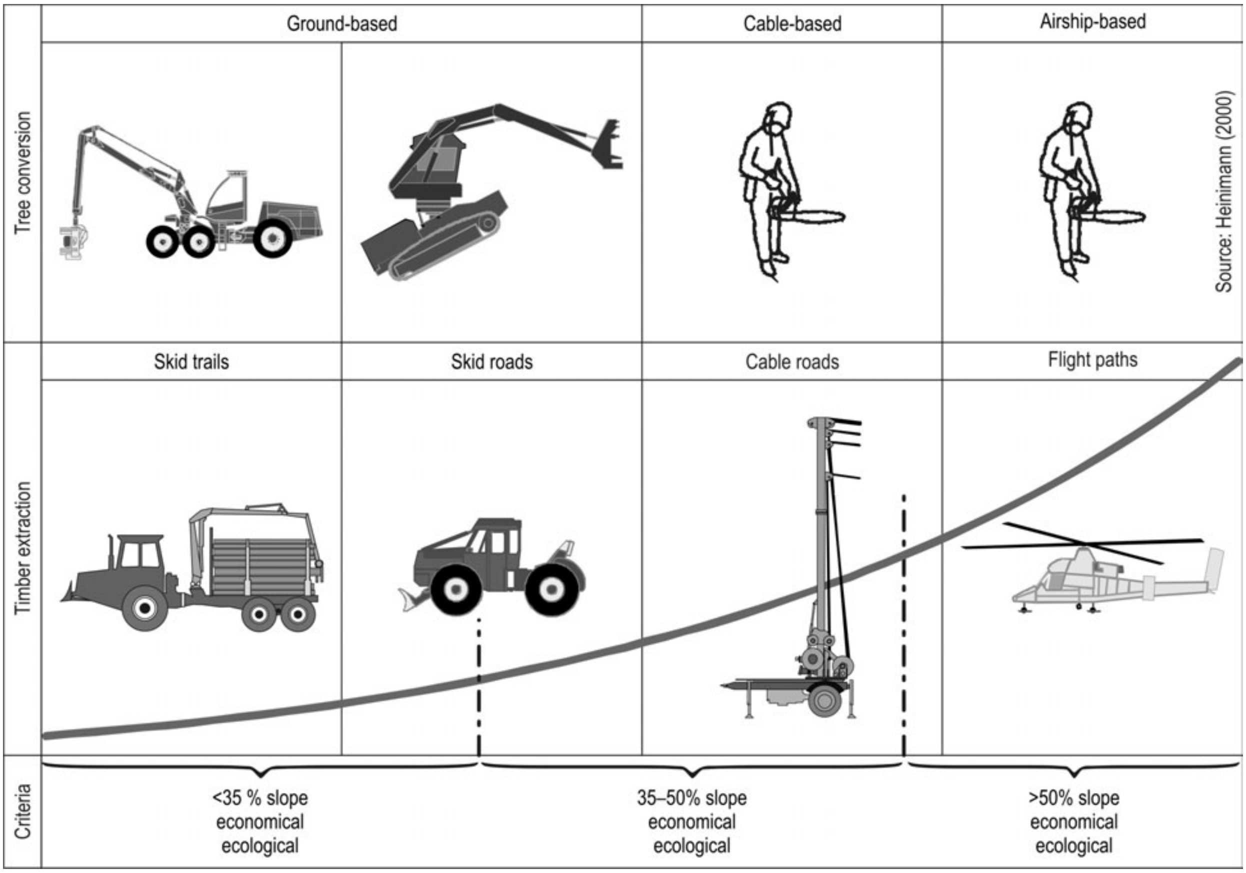

Figure 1. *Basic harvesting system concepts.*

area. Any individual component of the system can be changed without changing the harvesting method (i.e., the form in which wood is delivered to the roadside).

Rationalization efforts have resulted in ever-increasing mechanization of timber harvesting systems. The development and deployment of harvesting systems aim to provide bio-physically effective, economically efficient, individually compatible, environmentally sound and institutionally acceptable solutions *(1)*.

Heinimann *(2, 3)* selected four basic concepts of harvesting systems (Figure 1). Timber extraction could be performed with special forest vehicles (skidders and forwarders), cable yarders or helicopters. System complexity increases with the effort to ensure off-road locomotion. Skidders and forwarders may move off-road over natural terrain (skid trail) or, if the terrain conditions become too complex, over built skid roads. In difficult terrain conditions, cable yarders enable the transport of partially or fully suspended loads over large distances. The use of a helicopter for timber extraction is burdened with high operational costs, but could play an important role in timber transport in specific site conditions when road costs are high, the speed of operations is important or soil and stand damage must be avoided due to special functions of forests *(4, 5, 6, 7, 8)*.

Mechanization of felling and processing with harvesters was first performed on gentle terrain, and was gradually transferred to slopes. Availability of new technology (selflevelling wheeled platforms, legged platforms, platforms with four independent trapezoidal tracks) will make it possible to apply harvesters even on slopes up to 70% *(9, 10)*. Tree diameter (stump diameter) remains the main limiting factor of implementation, and restricts the operable use of harvesters up to 40 (50) cm of the breast height diameter *(11, 12, 13)*. To fell trees with breast height diameters over 40 cm, chainsaws are still necessary.

Ecoefficient mechanization of forest operations involves: 1) the efficiency of machine operations and 2) minimization of site impacts by machines used for timber harvesting *(14, 15, 16)*. While many studies have been conducted to evaluate physically feasible machine solutions and improve harvesting economics, environmental conservation assumed growing importance in public discussions. A harvesting method and machine type determine the types and extent of environmental consequences. The term »environmentally sound harvesting operations« implies the use of work methods and machinery that will cause only acceptable amount of damage to forest soil and stands, and will not disrupt the esthetic value of a forest working site.

Today's harvest planners operate in planning environment in which concerns over the adverse environmental impacts of timber harvesting activities must be

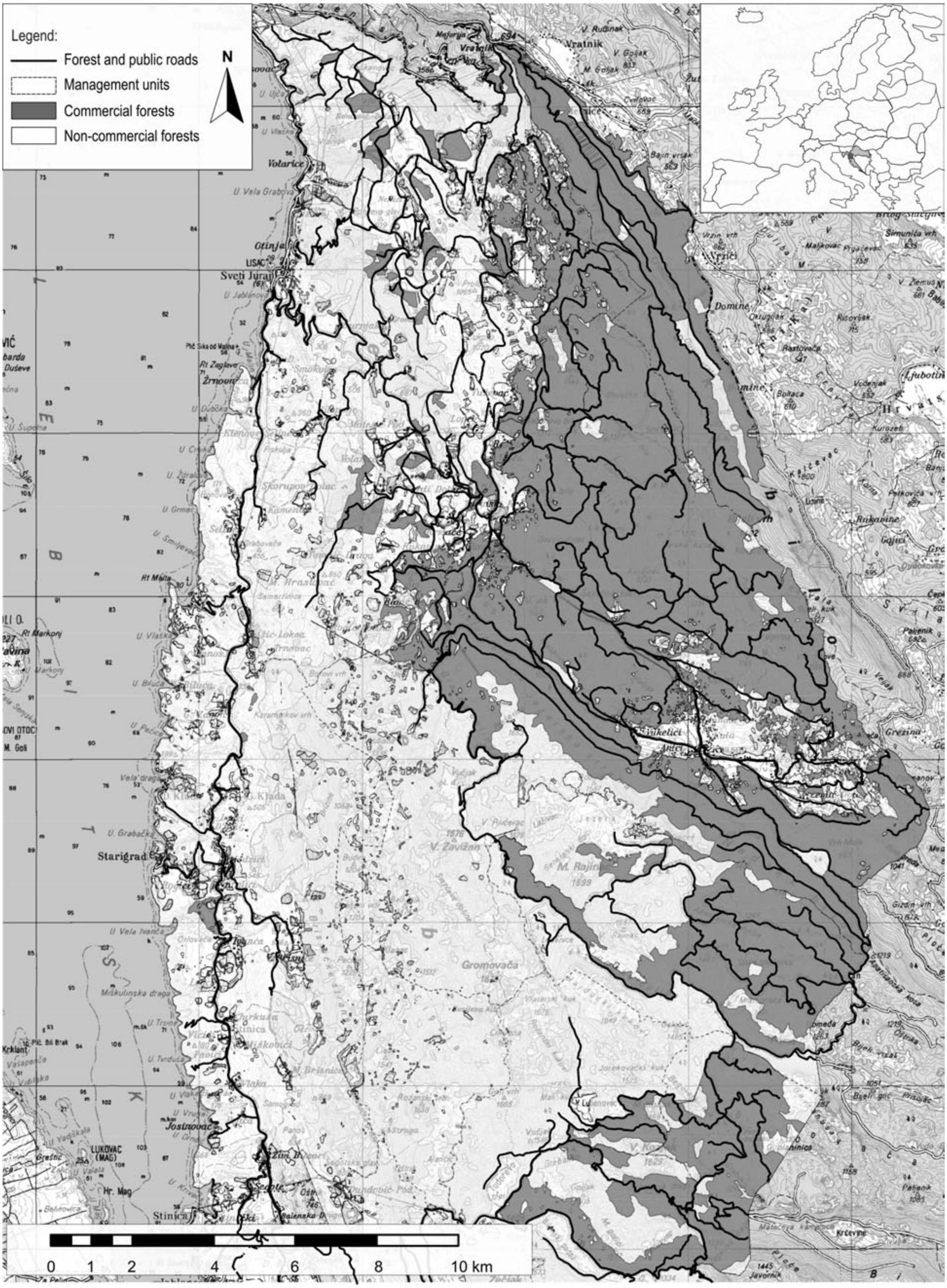

Figure 2. *Area of Northern Velebit.*

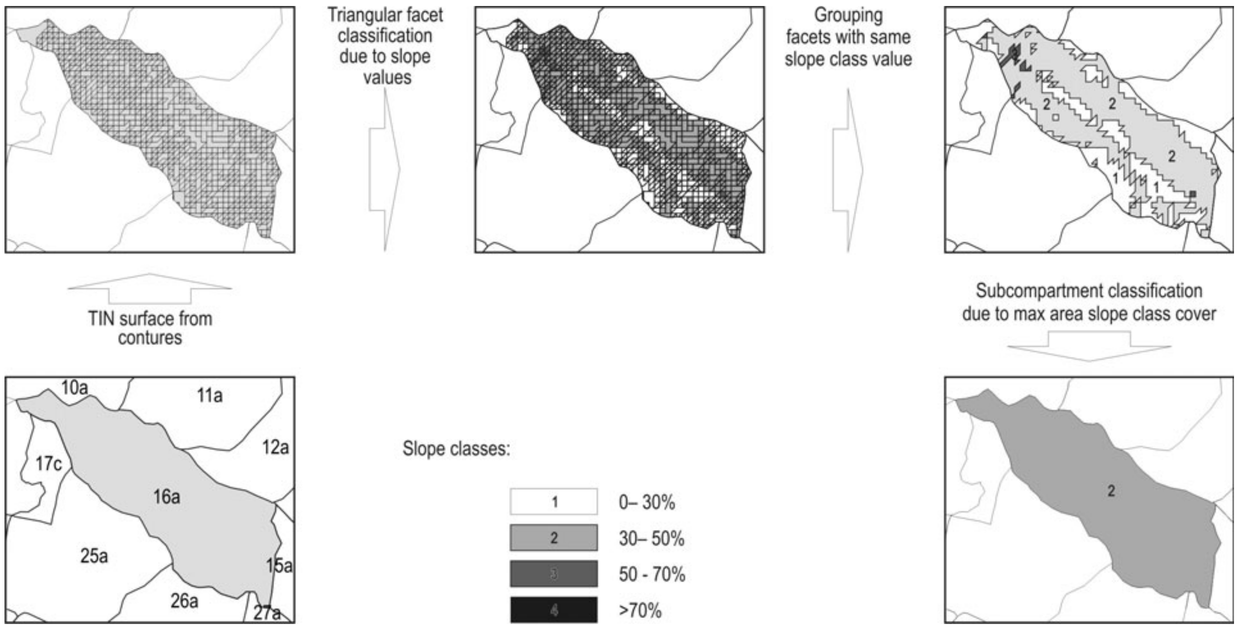

Figure 3. *Assessment of subcompartment slope class.*

balanced against the economic advantages of using highly mechanized harvesting systems *(17)*. In order to reduce the severity of these environmental impacts without significantly increasing harvesting cost, a harvest planner must consider site-specific terrain factors and equipment characteristics during harvest planning.

The main objective of terrain evaluation and classification in forest operations is the division of terrain into units which have the same or at least a similar degree of difficulty from the point of view of equipment suitability ratings *(18)*. There have been numerous attempts to develop a comprehensive terrain classification system for forest operations *(19, 20, 21, 22)*, but due to the development of machinery, data processing and society, older classification systems always seem to contain some deficiencies *(23)*. Two types of terrain evaluation systems have been used: descriptive classifications and functional classifications. In a descriptive classification system, a site is classified solely in terms of terrain factors (ground strength, surface roughness, and slope) that directly affect harvesting system productivity. In functional classifications, terrain is directly classified in terms of operability or inoperability of a particular type of equipment.

The paper aims: 1) to spatially describe forest (terrain, stand) properties using GIS analysis, 2) to develop a model (decision support system) for predicting eco-efficient forest harvesting.

MATERIAL AND METHODS

Geographically, the area of Northern Velebit is defined as a mountain massif extending from Senj to Jablanac *(24)*. This area is part of the Dinaric Alps with specific geo-morphological, climate and vegetation characteristics. The relief of Northern Velebit is characterized by carbonate rocks (limestone and dolomite) and their numerous karst forms: ridges, crests, crags, karst valleys, basins, transverse valleys, round karst valleys, cracks in limestone, caves, abysses, underground flows, karst wells.

Forests are the greatest natural phenomenon of Northern Velebit. This area (Figure 2.) comprises 46,160.69 ha of forests and forestland, of which 18,783.15 ha are commercial forests with high economic value *(25)*. »Northern Velebit« Nature Park extends over 10,937 ha of forest area, while protective forests and other special purpose forests cover 14,277.40 ha of the area. The most valuable commercial beech and fir forests are managed with the selective (group or individual) method in 10-year felling cycles.

A model for predicting eco-efficient forest harvesting has been made only for commercial forests of the Northern Velebit area. The main reason for this principle is attributed to intensive management of the mentioned forests. Due to special purposes of the surrounding protection forests and the forests of the National Park, harvesting technologies must be applied in the environmentally sound manner.

Research was conducted in 18 Forest Management Units of two Forest Offices (Krasno and Senj). The commonly used harvesting system in the study area includes motor-manual tree conversion by chainsaws and timber extraction over constructed skid roads by cable skidders *(26)*.

Multi-Criteria Evaluation method as a means of Land Suitability Analysis *(27, 28)* and decision support process was used for producing a model of predicting an eco-efficient harvesting system. Four main data sources were used for this purpose: 1) a digital elevation model (DEM), 2) a digital network of forest roads, 3) forest inventory data and 4) ecoefficient limitations for harvesting systems. Software ArcGIS 9 was used for GIS processing and data analysis.

A digital elevation model was made on the basis of topographic maps with contour line distances of 10 m. A triangulated irregular network (TIN) was created from the elevation data. Slope values were calculated for each triangular facet on the basis of a subcompartment and its boundary. A subcompartment slope map was obtained by grouping facets into 4 slope classes (0–30%, 30–50%, 50–70% and over 70% of inclination). According to the maximum area covered by the same slope class, the subcompartments were divided into classes (Figure 3.).

The basic forest inventory data and extraction distances data were taken from Forest management plans and analyzed for each forest subcompartment. Ground strength and surface roughness, as limitation factors of vehicle mobility, were not taken into consideration due to specific micro-relief characteristics (stoniness, rockiness and shallow soils originated on limestone) in the study area, where the problem of vehicle mobility was solved with the construction of a skid road network.

Effective management of machine mobility, control of site disturbances, and moderation of potential site damage due to harvesting machinery traffic require characterization of the effects of the site–machine interaction. This interaction should take into account the influence of machine variables on a wide range of forest terrains that may be encountered *(29)*. One aim is to understand the behavior of the machine–site interaction and provide threshold values to improve machine (system) mobility and efficiency *(30, 31, 32, 33, 34, 35, 36, 37, 38, 39)* and restrict possible damage to an acceptable level *(40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53)*.

Based on relevant and recent research on ecoefficient limitations of tree conversion and timber extraction, the seven main harvesting systems were selected for harvesting operations in the researched area (Figure 4.).

RESULTS

The model for determining a harvesting system in commercial forests of Northern Velebit is based on three influencing factors: terrain slope, extraction distance and breast height diameter of trees (Figure 5). Threshold values of influencing factors for classifying harvesting systems in the model are in accordance with ecoefficient limitations of tree conversion and timber extraction. Based on the model, a harvesting system was determined for each forest subcompartment.

The total analyzed area of commercial forests of Northern Velebit amounts to 13,902.5 ha and is divided into 606 forest subcompartments. The map of forest areas

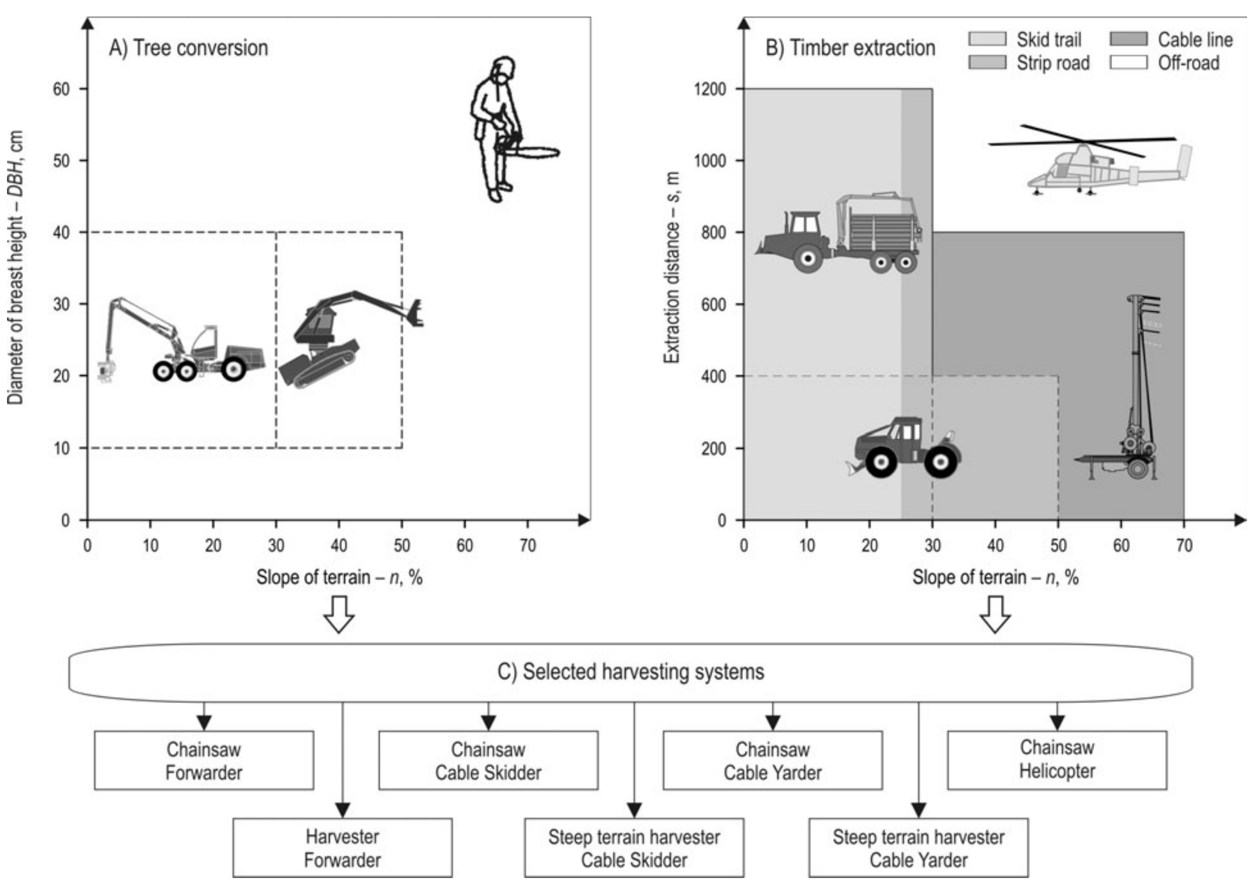

Figure 4. *Ecoefficient limitations of tree conversion and timber extraction with selected harvesting systems.*

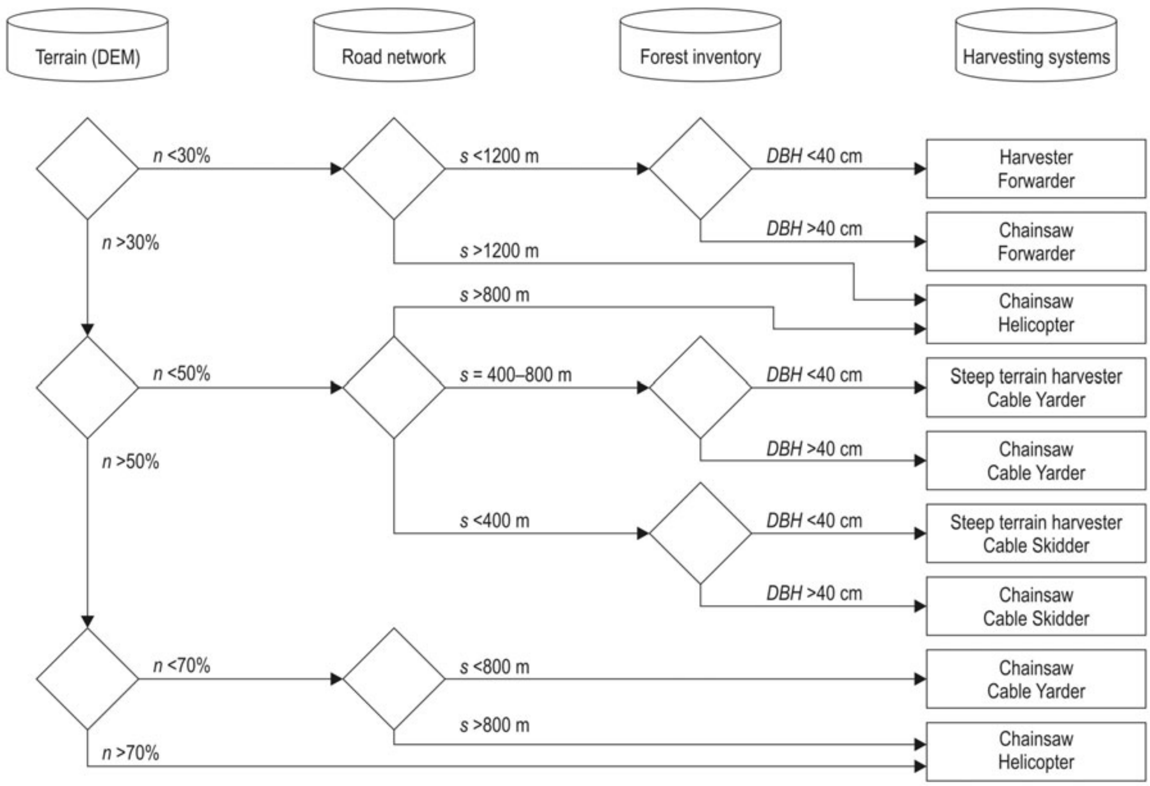

Figure 5. *Model for harvesting system determination.*

where the selected harvesting systems may operate is shown in Figure 6.

The most frequently used harvesting systems in the area of commercial forests of Northern Velebit are the steep terrain harvester – skidder (38.02% of the area) and chainsaw-skidder (36.21%). They are followed by chainsaw – cable yarder (8.85%), harvester – forwarder (7.27%), chainsaw – forwarder (6.55%), steep terrain harvester – cable yarder (2.56%), and chainsaw – helicopter (0.52%).

Fully mechanized harvesting systems (which could be described simply as „no man on the ground and no hand on the wood«), performed by harvesters and forwarders could be used over only 7.27% of the researched area.

Breast height tree diameter restricted mechanized felling and processing over 52.13% of the forest area.

Timber extraction distance, as the key influencing factor regarding off-road transport, is the result of the existing layout of road networks and forest subcompartments, which were planned and constructed in the past.

Due to a large number of subcompartments with slope up to 50% and the existing forest road network, ground-based extraction represents the main technology used over 88.57% of area.

To extract timber on slopes over 50%, only cable yarders or helicopters can be used. In the analysis, helicopter logging was suitable only over large distances and/or in very steep subcompartments situated on the tops of the mountain (0.52% of the area). Apart from terrain slope over 50%, the main reason for using cable yarders on 11.41% of the area is the length of the main line of 800 m (common to all types of current cable yarders).

DISCUSSION

In order to meet the requirements of environmental soundness, harvest planners need to consider site-specific terrain data for making decisions concerning the selection of a harvesting system. The model presented in the paper was developed as a tool for planning large-scale forest harvesting operations. It provides an efficient means of classifying forest stand conditions according to their influencing factors. In order to make functional terrain classification, a model for determining an ecoefficient harvesting system should comprise a geographic information system, and terrain and forest stand data. Based on terrain and forest stand data (slope, extraction distance, breast height tree diameter) and the limitations of forest machine performance, it is possible to create maps that determine areas in which each harvesting system may operate in environmentally sound manner and still be economically positive.

Such recommendations could clearly be made in the case of the area of Northern Velebit. Specific terrain (limestone combined with relief characteristics) and for-

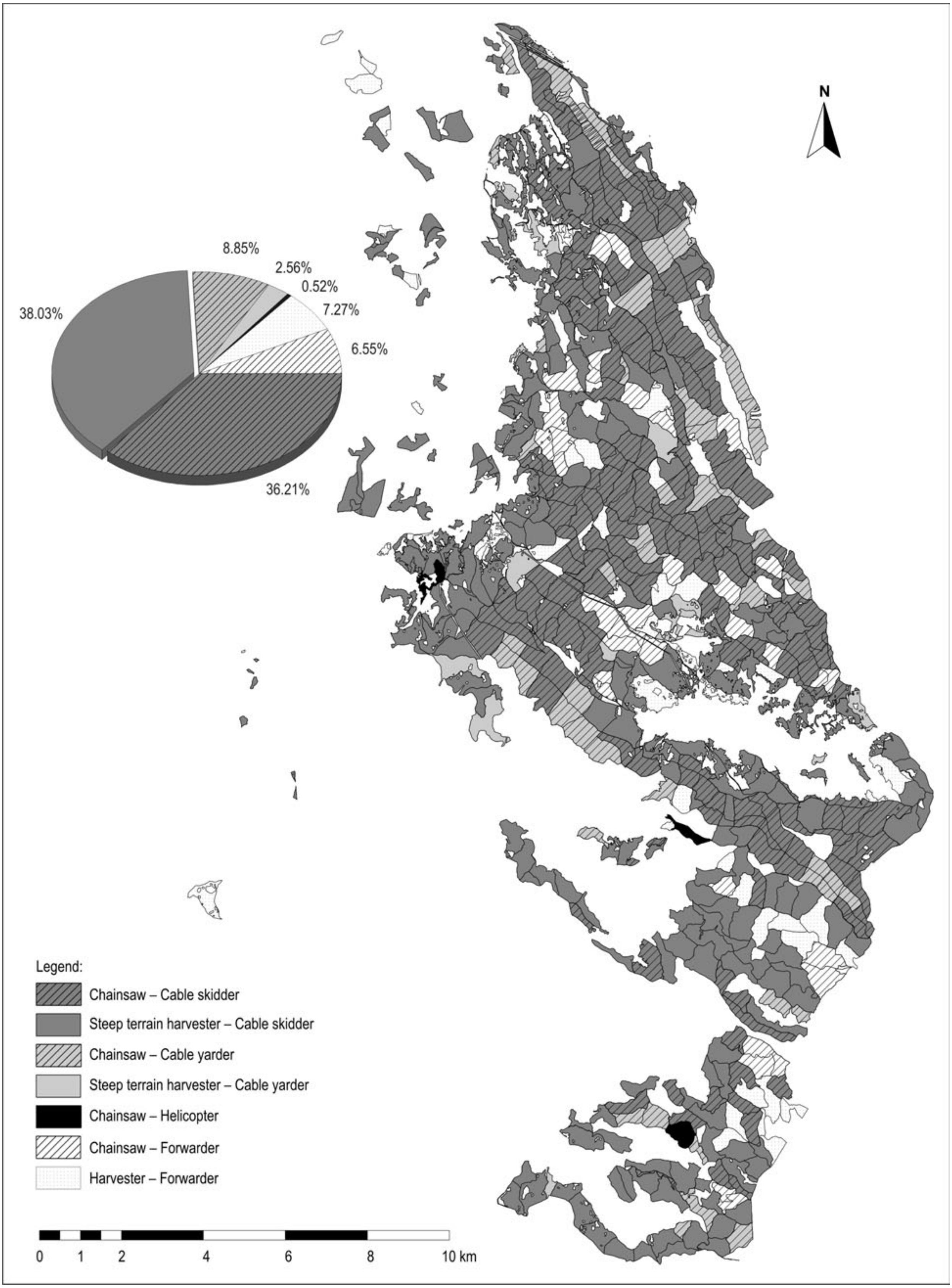

Figure 6. *Map of harvesting systems in the commercial forests of Northern Velebit.*

est stand conditions (mixed selective forests with natural regeneration) limit the application of some harvesting systems which would otherwise be environmentally acceptable in many other cases.

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